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On the applicability of the effective medium approximation to the photoacoustic response of multilayered structures

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Abstract

If the model of the photoacoustic (PA) response of an investigated system contains many unknown parameters, as is the case with multilayered samples, then the inverse procedure for the calculation of the parameters is highly sensitive to experimental noise. The problem cannot be solved by developing the experimental setup or by data acquisition methods, but only by an improvement of the theoretical approach. This paper presents an analysis of the applicability of the effective medium approximation to the PA response of multilayered samples. It has been shown that the theory is not applicable to the general case, and explicit expressions for the effective values of thermal diffusivity and heat propagation speed have been derived for some special cases.

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1. Introduction

The vast production and application of materials with multilayered structures have motivated extensive studies of their properties. One of the common research goals is to produce the behaviour of a multilayered structure on the basis of the behaviour of individual layers. Among the most important physical properties studied are thermophysical properties, because the ability, for example, to predict the behaviour of a semiconductor heterostructure on the basis of the thermal characteristics of constituent layers which enables the prediction of the performance of various types of microelectronic and optoelectronic devices during heating and consequently enables the estimation of their lifetime [1].

Over the last three decades, several methods have been developed for the calculation of thermal transport properties with high precision by photoacoustic (PA) experiments based on indirect PA generation [2–4]. In these experiments, an acoustic wave is generated in a coupling medium (typically air) around the sample, usually due to heat

leakage and acoustic transmission from the sample [2]. The measured acoustic signal, originating from the propagation and scattering of thermal waves caused by the absorption of an intensity-modulated laser beam, carries information on the optical and dynamic thermal properties of the material of the sample, as well as on its geometry. In order to calculate these properties of the sample, the first step is to solve the so-called forward problem, i.e. to determine the dependence of the PA response of the sample on its geometrical, optical and thermal properties, as well as the intensity and modulation frequency of the incident optical beam. This task has already been performed for one-layered samples with simple geometries: planes, cylinders and spheres [5–8], and for some two-layered [9–12] and multilayered structures [13–15]. The second step requires the development of an inverse procedure for the calculation of physical properties of the sample from the measured PA response when the intensity and modulation frequency of the incident optical beam are known. Mathematically, it is an ill-conditioned problem, meaning that small variations in the input data (that may

